TR-1119

A MICROMINIATURE AMPLIFIER WITH THIN-FILM PASSIVE PARTS

B. Mermelstein

W.C. Boesman

26 April 1963

HARRY DIAMOND LABORATORIES
FORMERLY: DIAMOND ORDNANCE FUZE LABORATORIES
ARMY MATERIEL COMMAND
WASHINGTON 25, D. C.

HARRY DIAMOND LABORATORIES

Robert W. McEvoy
LtCol, Ord Corps
Commanding

B. M. Horton
Technical Director

MISSION

The mission of the Harry Diamond Laboratories is:

(1) To perform research and engineering on systems for detecting, locating, and evaluating targets; for accomplishing safing, arming, and munition control functions; and for providing initiation signals: these systems include, but are not limited to, radio and non-radio proximity fuzes, predictor-computer fuzes, electronic timers, electrically-initiated fuzes, and related items.

(2) To perform research and engineering in fluid amplification and fluid-actuated control systems.

(3) To perform research and engineering in instrumentation and measurement in support of the above.

(4) To perform research and engineering in order to achieve maximum immunity of systems to adverse influences, including countermeasures, nuclear radiation, battlefield conditions, and high-altitude and space environments.

(5) To perform research and engineering on materials, components, and subsystems in support of above.

(6) To conduct basic research in the physical sciences in support of the above.

(7) To provide consultative services to other Government agencies when requested.

(8) To carry out special projects lying within installation competence upon approval by the Director of Research and Development, Army Materiel Command.

(9) To maintain a high degree of competence in the application of the physical sciences to the solution of military problems.

UNITED STATES ARMY MATERIEL COMMAND
HARRY DIAMOND LABORATORIES
WASHINGTON 25, D.C.

NAS-W-251
AMCMS-5010.21.83701
HDL 94892

TR-1119

26 April 1963

A MICROMINIATURE AMPLIFIER WITH THIN-FILM PASSIVE PARTS

B. Mermelstein

W. C. Boesman

FOR THE COMMANDER:
Approved by

P. E. Landis
Chief, Laboratory 900

Qualified requesters may obtain copies of this report from ASTIA.

CONTENTS

ILLUSTRATIONS

FIGURES

ABSTRACT

A microminiature 30-Mc IF amplifier stage was fabricated from vacuum-deposited thin-film passive components and two inserted parts. The vacuum-deposited parts, thin films of nickel-chromium, aluminum, and silicon monoxide, were laid down for use as resistors, conductors and dielectrics, respectively. In the deposition processes, dimensionally accurate masks are essential and they were achieved by the use of a spark erosion technique. A specially designed mask-and-substrate holder accurately indexed the masks relative to the substrates.

Three models of this amplifier were made but one could not be used due to a short in the circuit. The other two circuits showed gains of 16.5 and 14.7 db. When one circuit was retested after storage in a desiccator for one year at room temperature, the gain was 15.1 db.

This amplifier represents the first HDL operating device to employ vacuum-deposited conductors, resistors, and capacitors.

1. INTRODUCTION

In prior work at HDL, a miniature 30-Mc IF amplifier had been constructed by Yetter and Hall (ref 1) in a 2D form using etched wiring, printed resistors, and inserted capacitors, coils, and transistors. Simultaneous development of vacuum-deposited, thin-film conductors, resistors, and dielectrics was in progress (ref 2,3) with the objective of eventual application in microminiature circuits. As a combination and extension of these two efforts, a 30-Mc IF amplifier stage was chosen for fabrication by thin-film techniques. In the new thin-film device, the resistors, conductors, and dielectrics were to be vacuum deposited onto the substrate but, failing techniques for vacuum deposition of transformers and transistors, these latter parts would still have to be inserted into the substrate.

2. EXPERIMENTAL METHODS

2.1 Design of the Amplifier

Based on the prior vacuum evaporation work, the materials chosen for the thin-film conductors, resistors, and dielectrics were aluminum, 80 percent nickel: 20 percent chromium, and silicon monoxide, respectively. The aluminum conductors were planned in thicknesses to give resistances less than 0.5 ohm per square.

The resistors and capacitors had to be designed to give the resistance and capacitance values required by the 30-Mc IF amplifier circuit, shown in figure 1. Satisfaction of this requirement involved first, selection of the minimum film thickness compatible with homogeneity of the film, next, selection of width, next, calculations of lengths for resistors and of areas for capacitors, and finally, layout of the thin-film circuit design shown in figure 2.

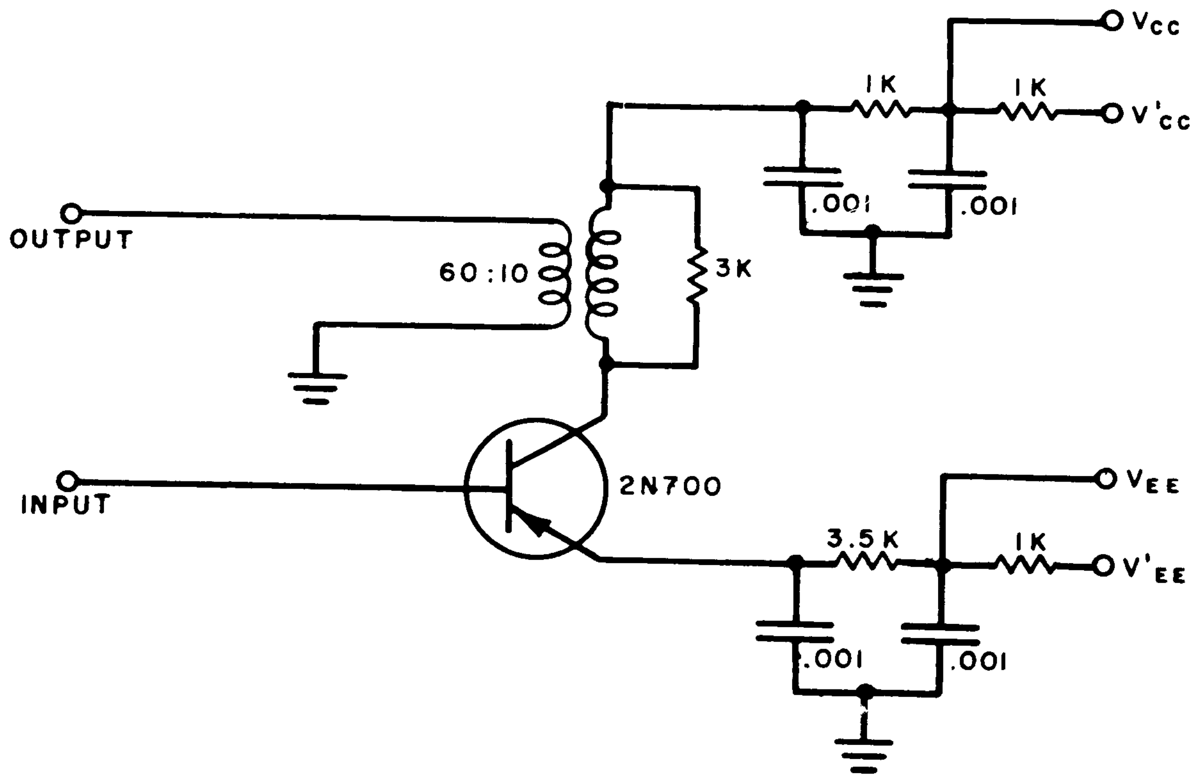


Figure 1. Schematic diagram of the 30-Mc IF amplifier circuit.

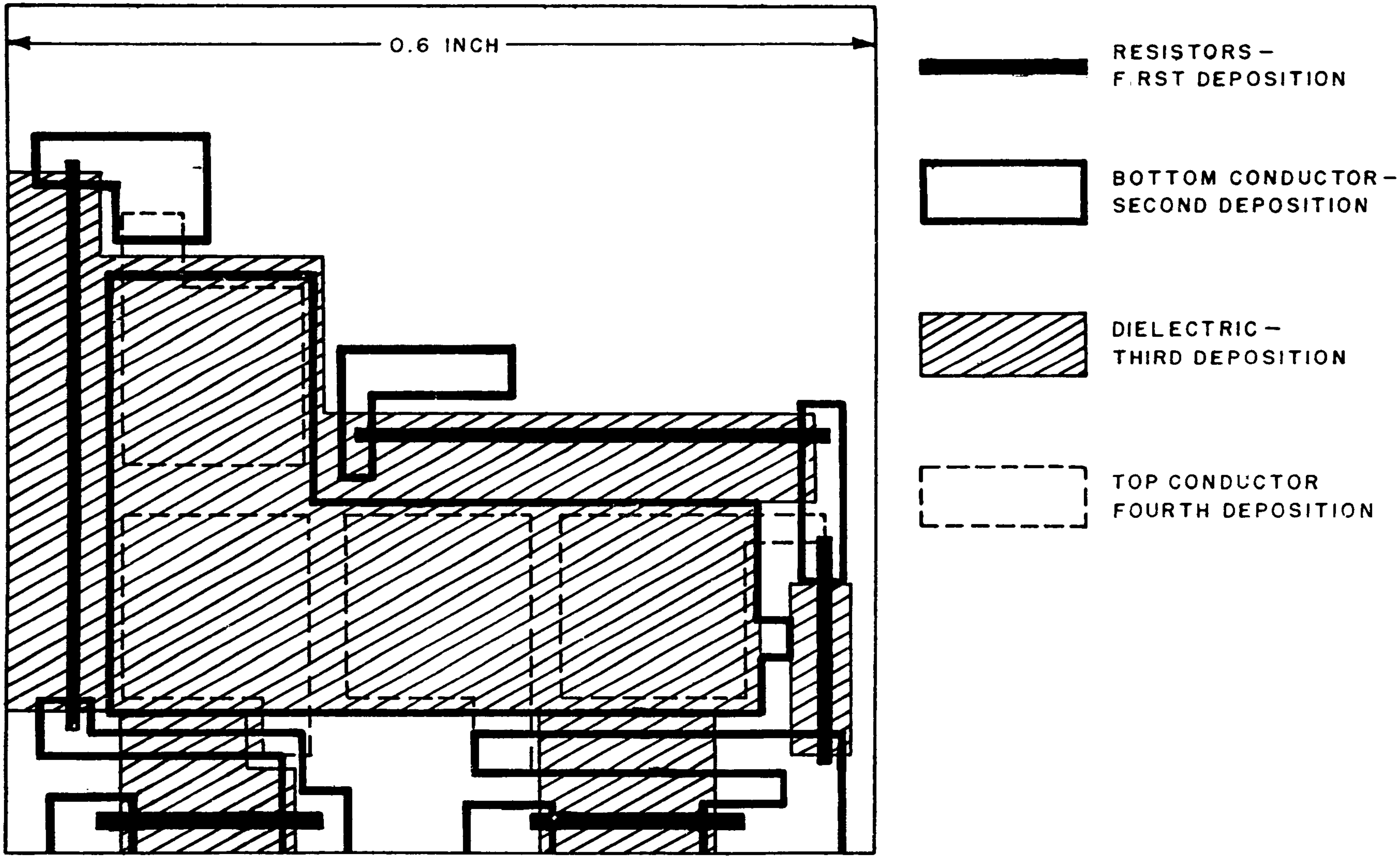


Figure 2. Thin-film 30-Mc IF amplifier circuit layout.

The 30-Mc IF amplifier stage required five resistors, three with values of 1000 ohms, one of 3000 ohms, and one of 3600 ohms. Since the minimum-thickness nickel-chromium film gives a resistance value, σ (see below), of about 100 ohms per square of resistance area, and the resistors were planned in 0.010-in. widths on a 0.6-in.-square glass substrate, required resistor lengths were calculated from the following formula:

$$\ell = RW/\sigma$$

where

ℓ = length of resistor, in in.

R = resistance, in ohms

σ = resistance/sq., in ohms/sq.

w = width of resistor, in in.

Another consideration in planning these small-area thin-film resistors was power dissipation of the thin film. This can be a problem because of the small radiating surface involved. However, it was known (ref 2) that the resistors, as designed for this thin-film circuit, had sufficient area to dissipate the available power.

The amplifier stage required four 0.001-μf capacitors. The dielectric constant, K, for an SiO thin-film dielectric (5000 Å in thickness) varies from 5 to 7 depending upon the conditions of deposition; and previous work had shown 5 to be the figure more applicable to such films made at HDL. Hence, the required area of a 5000-Å-thick, 0.001-μf SiO dielectric was calculated, using the following formula

$$A = \frac{dC}{0.0855K}$$

where

A = area, in cm^2

d = dielectric thickness, in cm

C = capacitance, in $\mu f \times 10^{-6}$

K = dielectric constant

and was found to be 0.1129 cm^2.

2.2 Preparation of Mask-and-Substrate Holder

Since the thin-film parts must have close dimensional tolerances, a device was necessary to position and hold the masks precisely relative to the substrates. Such a holder was designed and is shown in figure 3. This holder was designed to hold up to ten substrates and masks. It is basically a stainless steel plate, 7 in. in diameter, to which can be screwed the ten individual mask-and-substrate holders.

The ten small individual holders are stainless steel discs, 1.25 in. in diameter, the top and bottom halves each being 1/8 in. thick (fig. 4). They were milled to provide a recess for the glass substrates used in this work. This recess was 0.600 ± 0.0005 in. square, and 0.046 in. deep. A stainless steel mask (also shown in fig. 4) was normally placed over the glass substrate in the recess. The mask was held in its proper lateral position by means of indexing pins, and at the same time was held firmly against the substrate by means of spring clips.

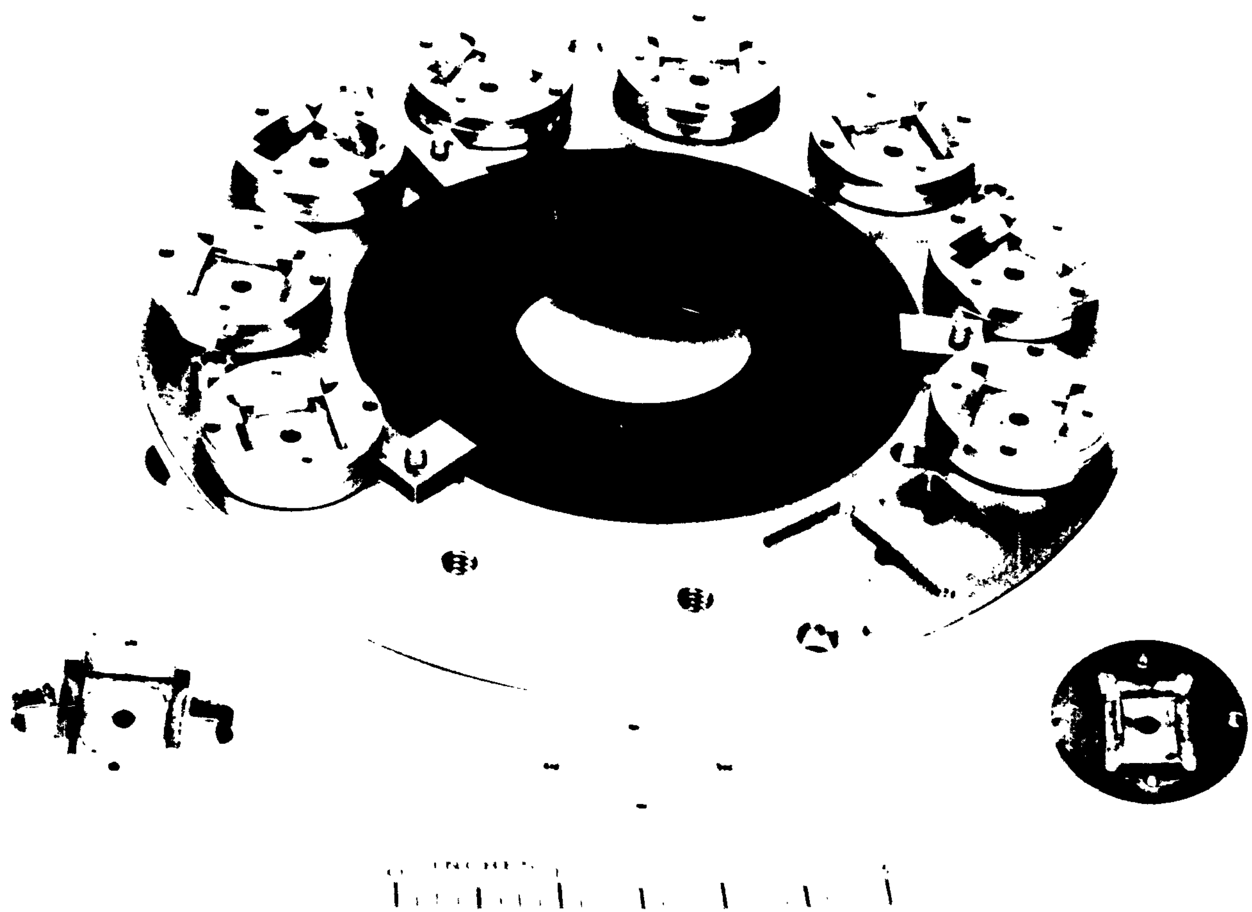
A circular heater was also attached to the 7-in. plate and was capable of heating the substrates to 300°C.

2.3 Preparation of Stainless-Steel Masks

As indicated in figure 2, four different masks were needed in the fabrication of one 30-Mc amplifier circuit. Slot widths were required to be as narrow as 0.010 in.

The masks were made from 0.002 in.-thick stainless-steel shim-stock blanks using a spark-erosion machine. The mask-blank and a copper electrode were connected in the same electric circuit, and the electrode was spaced from the workpiece at the required distance for a spark to be generated in the gap. This entire system was immersed in a dielectric liquid, which prevented combustion and acted as a cooling agent. The electrical breakdown of this dielectric liquid led to a spark that produced local melting, and partial evaporation of the surface metal, thus producing erosion in both electrodes. The copper electrode had a male shape corresponding to the shape of the hole or recess to be formed in the blank. As the work was eroded by sparking, the copper electrode was advanced to maintain the spark gap, and was continually readvanced until it had penetrated as far as required into the blank.

A fixture was prepared to aid in the exact positioning of the spark-eroded slots in the stainless-steel masks. The fixture employed six pins having diameters of 0.062 in., two were for mask-locating, and corresponded to the mask-locating pins in the mask-and-substrate holder, the remaining four pins were used with polytetrafluoroethylene gage blocks to accurately guide the spark erosion electrodes to their required position above the stainless-steel mask blank. Twelve masks were prepared at one time by allowing the spark erosion machine to spark through a stack of twelve blanks.



478-61

Figure 3. Multiple mask-and-substrate holder.

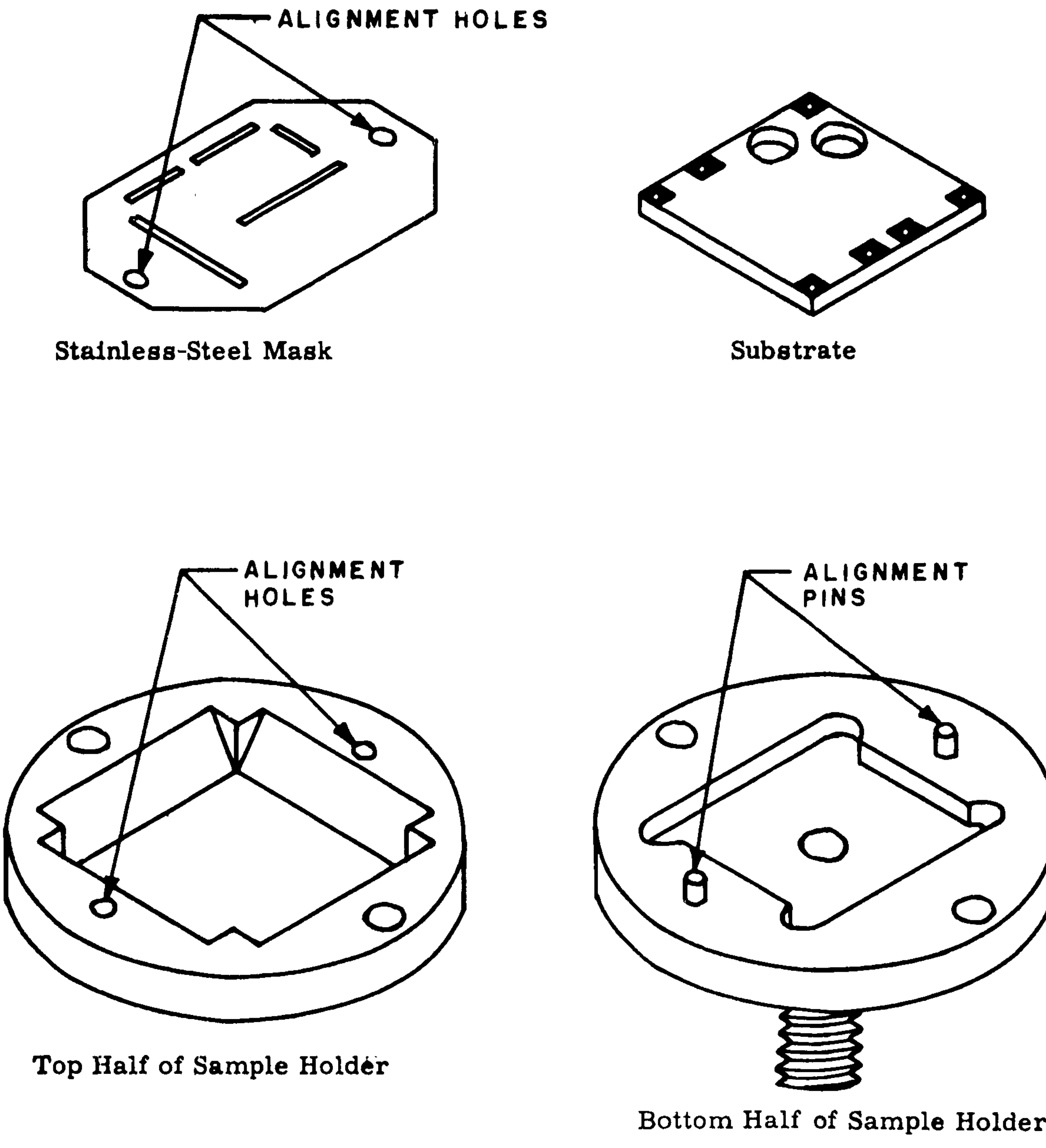


Figure 4. Mask, substrate, and individual mask-and-substrate holder.

An 0.010-in.-wide line in the stack of twelve masks was checked on a shadowgraph of magnification 10X. The widths of this line in the first (top), third, sixth, ninth and twelfth (bottom) mask were compared.

2.4 Preparation of Glass Substrates

Glass substrates were prepared in the dimensions 0.6 in. by 0.6 in. by 0.040 in. Circular holes were provided in the substrates for insertion of a transistor, a toroid, and lead-out wires. The diameters of the holes for the transistor and toroid were 0.190 in. and 0.175 in., respectively. These holes were made by an ultrasonic grinding technique described by Krawczyk (ref 4).

Next, the substrates were cleaned, first in an ethyl alcohol vapor bath and then by a hot chloroform spray. The time between spraying the substrates with hot chloroform and deposition of resistors on them in an evacuated vacuum chamber was always kept to a minimum. The final cleaning operation was accomplished by glow discharge bombardment in the partially evacuated vacuum chamber (ref 5).

2.5 Deposition of Resistors

The resistor masks, as well as all other masks used in this study, were cleaned in the same manner as the glass substrates, i.e., in an ethyl alcohol vapor bath followed by a hot chloroform spray. Immediately after cleaning, the substrates and masks were placed in their holders and inserted into the vacuum chamber.

With the pressure at 0.04 torr, a glow discharge was initiated. The glow discharge was maintained for 3 min at a potential of 2 to 3 kv and a current of 100 to 150 ma. During this time, the pressure varied over the range 0.02 to 0.04 torr. The pressure was then allowed to fall to 5 x 10^{-5} torr while the glass substrates were heated by the circular resistance element located in the center of the mask-and-substrate holder plate. The temperature of the substrates was held at 300°C during the deposition of the nickel-chromium resistors.

The apparatus used in the vacuum chamber for the deposition of nickel-chromium resistors consisted of the bell shaker-type arrangement shown in figure 5. This shaker is a modified version of a shaker used by Moll (ref 6). This bell shaker system permitted pellets of 80 percent nickel, 20 percent chromium to be shaken, a few at a time, onto a white hot tungsten boat, thereby causing "flash" or instantaneous evaporation of the nickel-chromium pellets. This technique can be expected to yield films of reasonably uniform composition, as distinguished from films built up in a graduated ratio of nickel to chromium resulting from the difference in vapor pressure of the two metals. In addition, flashing lessened the chance of contaminating the films with the boat material (tungsten) because the nickel-chromium pellets remained in contact with the tungsten boat for only an instant before they were evaporated.

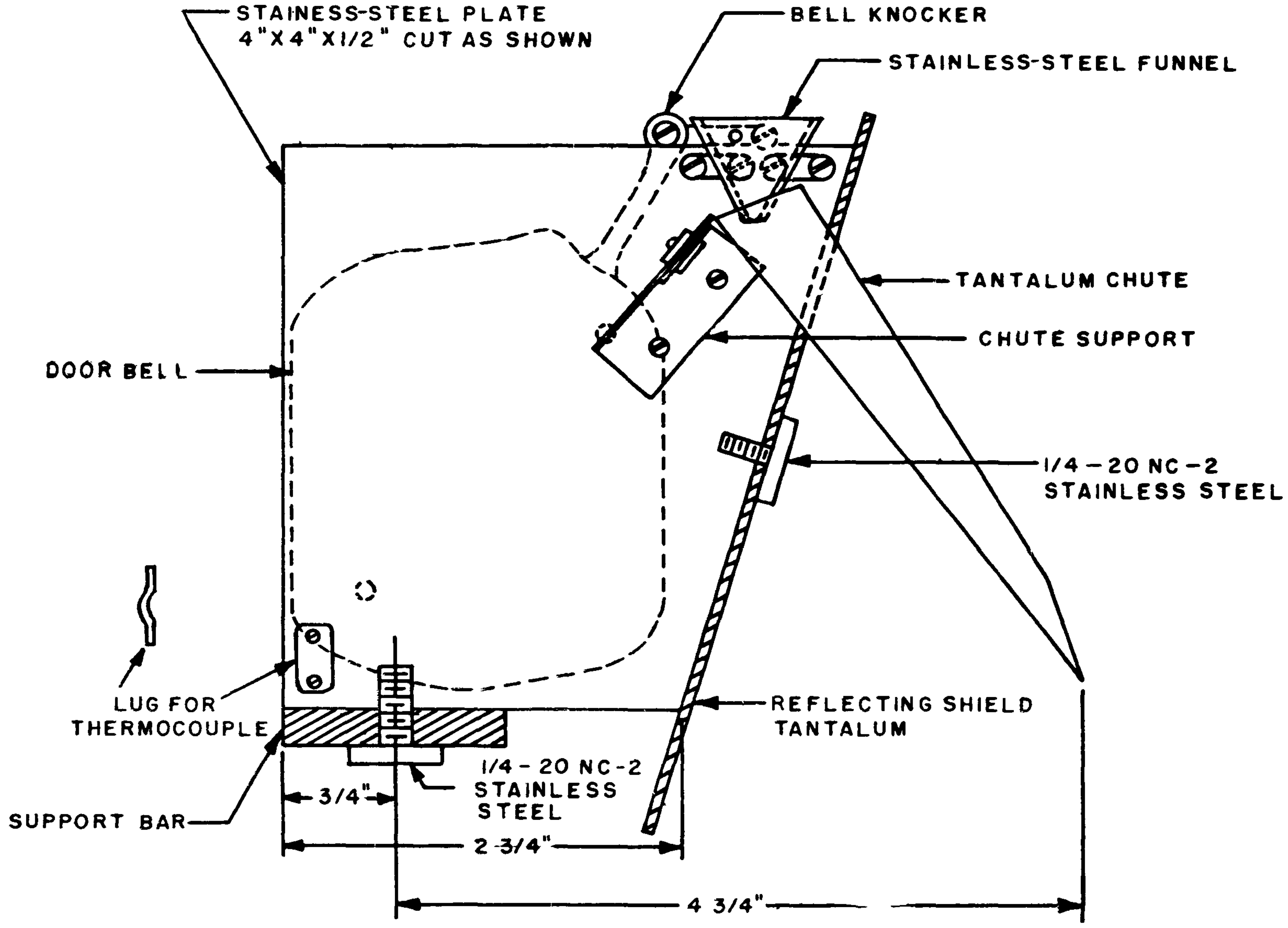


Figure 5. Diagram of bell shaker for flash evaporation.

In order to monitor the resistance values of the nickel-chromium films as they were being deposited, a glass monitor slide was placed on the holder plate at the same distance from the source as the mask-and-substrate holders. The area dimensions of this monitor slide were 0.5 in. by 1.0 in., and it was provided with 0.25-in.-wide gold electrodes at either end to which pressure contact was made. The leads from the pressure contact were brought out of the vacuum chamber and connected to an ohmmeter.

The deposition of nickel-chromium continued until the resistance of the monitor reached a value of 90 ohms. Since the resistor area was square in shape, this value could also be expressed as ohms per square. The evaporation was stopped and the substrates were allowed to cool to room temperature before the chamber was opened to the atmosphere.

These resistors were annealed for 10 min at 250°C in air.

2.6 Deposition of Bottom Conductor Pattern

The masks for the bottom conductor pattern were cleaned in solvent in the same manner as that described previously, positioned over the substrates in the mask-and-substrate holder, and the assemblies were immediately placed in the vacuum chamber. The pressure was lowered to 0.04 torr and the substrates were glow-discharge cleaned for 3 min as described above in the procedure for resistor deposition.

Following the glow discharge, the pressure was lowered to 5×10^{-5} torr. At this pressure, aluminum was thermally evaporated from a resistance-heated molybdenum boat onto the room-temperature substrates.

In this evaporation, the resistance of the aluminum conductors was not monitored as in the case of the nickel-chromium resistors. Instead, a "charge" of 125 mg of aluminum wire was carefully weighed out before the evaporation. This charge was then evaporated to completion. It was known from many previous aluminum evaporations that this amount of charge, at the boat-substrate distance (20 cm) being used, would give an adequately thick conducting element.

2.7 Deposition of the Silicon Monoxide Dielectric

The masks for the dielectric were cleaned in solvent in the same way as were the masks for the resistors and conductors. The glow discharge cleaning of the glass substrates was also carried out in the same manner as that described in the procedure for the deposition of the resistors and conductors.

The apparatus used in the evaporation of silicon monoxide (SiO) (fig. 6) was a modification of that described by Drumheller (ref 7). In essence, this cylindrical vaporizer is designed to insure that the substrates "see" only the SiO vapor that passes into the inner perforated

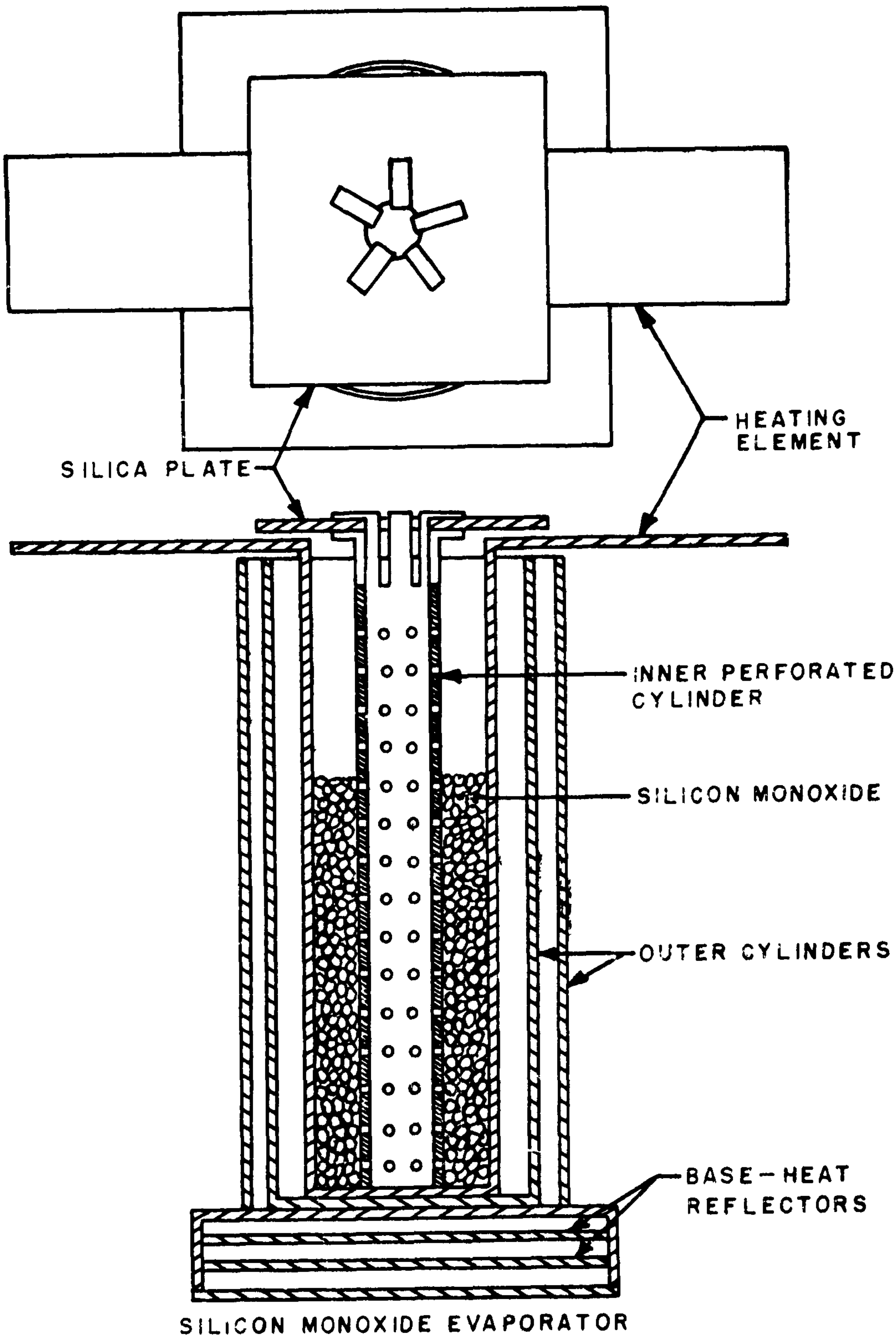


Figure 6. Diagram of silicon monoxide cylindrical evaporator.

cylinder, and not the SiO particles resulting from the violent spitting that is often observed during the evaporation of SiO. This apparatus was made of tantalum.

After the glow-discharge cleaning of the substrates, the pressure was lowered to 5×10^{-5} torr and the SiO evaporator was slowly heated until the SiO was at 1200°C. The temperature was measured by a thermocouple inserted through the outer cylinders and pressed securely against the inner cylinder. This heating was done slowly to enable the pumps to hold the pressure at about 5×10^{-5} torr, in the face of the increased outgassing of the SiO as it was being heated. The substrates were protected from any SiO vapor during this heating-up period by means of a shutter (not shown in fig. 6) placed directly over the opening of the tantalum cylinder. This shutter was not removed until the temperature of the SiO reached 1200°C and the pressure was less than or equal to 5×10^{-5} torr. When these two conditions were met, the shutter was removed and the evaporation and deposition allowed to proceed unhampered for 3 min , at which time the shutter was again placed over the tantalum source and the SiO allowed to cool.

2.8 Deposition of the Top Conductor Pattern

This procedure was the same in every detail as that for the bottom conductor, except for the use of different masks.

2.9 Insertion of Prefabricated Components and Completion of Amplifier

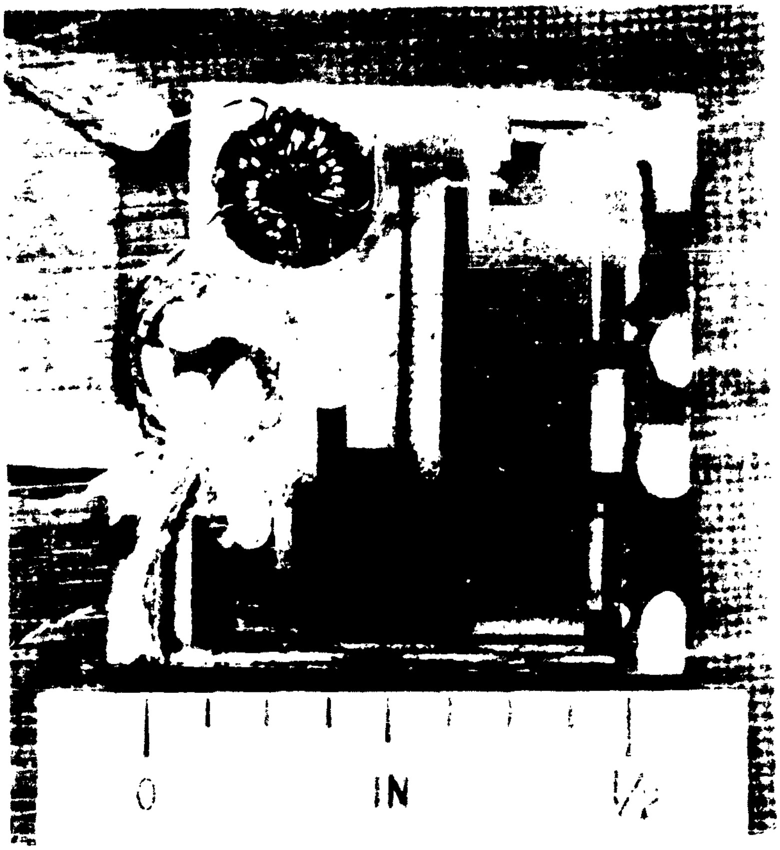
In addition to the thin-film components, there are in this circuit a hand-wound coil, and a 2N700 commercial transistor that had been decased, potted, and sliced in order to package the active part in flat form, as is described fully in reference 1. After the deposition of the thin-film components, these two prefabricated components were inserted into their respective holes in the substrate. They were held in position by an air-dried polystyrene-base adhesive. The connections between the inserted components and the thin-film components were made with a silver-filled epoxy resin conductive adhesive described by Kilduff and Benderly (ref 8).

The conductive adhesive was also used to connect the lead-out wires (number 38 copper wire) to the thin-film conductors. The lead-out wire was first inserted through the lead out holes and then twisted to make a strong mechanical joint.

The completed 30-Mc IF amplifier is shown in figure 7. Three models were constructed.

2.10 Testing of Parts and of the 30-Mc IF Amplifier Stage

Resistors and Conductors: Resistance was measured by means of an ohmmeter. Contact was made to the films with metal probes.



1864-61

Figure 7. Microminiature 30-Mc IF amplifier stage with thin-film passive parts.

Capacitors: Capacitance was measured on the 30-Mc IF amplifier substrate at 1000 cps using a standard capacitance bridge. Contact was made to the films with metal probes.

Gain Measurements on the 30-Mc Amplifier Stage: A signal generator was connected to the thin-film amplifier stage through a 50-ohm generator impedance, the input voltage being read directly from the signal generator. The output of the stage was then connected to an rf voltmeter across a 50-ohm load. The gain was read directly from the rf voltmeter. Connection was made to the stage by means of the lead-out wires.

One of the amplifier stages was retested after storage for one year in a desiccator.

3. DISCUSSION

3.1 Design

Minimal thicknesses of resistive and dielectric films are desirable because they yield highest valued resistors and capacitors, respectively, per unit of surface area. Extreme thinness, however, is limited as follows:

(a) Nickel-chromium resistor films with thickness less than 100 Å tend to be porous, discontinuous, and greatly affected by the surface condition of the substrate on which they have been deposited. These properties, coupled with a high surface-to-bulk ratio, lead to instability of the film due to oxidation and recrystallization.

(b) Silicon monoxide dielectric films tend to be porous at thicknesses less than 4000 or 5000 Å; in the case of deposited capacitors, porosity would result in short-circuiting of the deposited upper electrode to the base or, at the very least, a reduction in the effective breakdown strength of the capacitor.

3.2 Mask-and-Substrate Holder

The purpose of the mask-and-substrate holder was four-fold. First, it had to provide for fast, easy mask changing. This was necessary to insure that the substrates were exposed to the atmosphere for a minimum amount of time between evaporations. Second, each mask had to be placed in an exact position relative to the patterns deposited through other masks onto the same substrate. This was accomplished by means of indexing pins. Third, the masks had to be securely pressed against the substrate during the evaporation in order to obtain sharp-edged patterns. The spring clips provided adequate pressure. Last, the substrates had to be held against the mask-and-substrate holder with enough force to insure good thermal contact when the substrates were heated. The spring clips were adequate for this purpose also.

3.3 Stainless-Steel Masks

Stainless steel was used for the masks because it is rigid and does not sputter under glow-discharge bombardment. The spark erosion technique, a new approach for making masks at HDL, was used because, thereby, masks can be made readily from stainless steel within the tolerances required for this work. The shadowgraph measurements on the 0.010-in.-wide line, made with the spark erosion machine, showed that there was only a 0.0003-in. difference between the width of the 0.010-in. line on the first and on the twelfth mask. The differences in the intervening masks were smaller. The edges of all the lines appeared to be sharp.

3.4 Glass Substrates

It is important to achieve extreme cleanliness of the substrates in vacuum-evaporation work. This is necessary first to insure adequate adherence of the deposited layers to the substrate and to each other, and second, to insure removal of dust particles that may be one of the factors that cause pin holes.

As noted previously, the substrates were cleaned by both chemical and positive-ion-bombardment processes. These procedures were followed because, even though many contaminants, especially oils, salts, etc, are removed from the substrates by conventional chemical cleaning techniques, there is an unavoidable exposure of the substrates to the atmosphere after cleaning and before the evacuation of the vacuum chamber. This exposure is sufficient to recontaminate the substrate surfaces, especially with surface moisture and dust particles. Hence, the final cleaning step, the ion bombardment, was made just prior to the deposition of the thin-film component. This ion bombardment cleaning is useful both in heating the substrates, thereby volatilizing surface moisture and other volatiles, removing other contaminants that neither heat alone, nor the chemical cleaning, can remove (ref 5).

3.5 Vacuum-Deposited Resistors

An alloy of nickel (80%) chromium (20%) was one of the first thin-film resistive materials investigated at HDL (ref 2,9) and was the one chosen for the resistor elements of the 30-Mc IF amplifier.

Nickel-chromium (Ni-Cr) films having resistance values of about 100 ohms per square yielded resistors that would fit on a 0.6-in.-square plate when their width was 0.010 in.; and these resistors were relatively stable with time and temperature. Such films, being in the 100-to-200 Å thickness range, were easily deposited in a short time (2 to 3 min.).

The substrates were held at 300°C during the resistor deposition because a hot substrate aids in the adhesion of Ni-Cr films to glass. A hot substrate is believed to cause oxidation of the layer at the Ni-Cr film/glass substrate interface, and this layer is thought to effect adhesion between the two surfaces (ref 10). The heat treatment in vacuum also aided in the stabilization of the resistor values with time, due to the enhancement of well ordered crystal structures by the heat treatment.

Deposition of the resistive film was continued until its resistance value reached about 90 ohms per square, instead of the 100 ohms per square desired, because this procedure allowed for a small increase in resistance due to the 10-min. post annealing at 250°C in air, and further small increases due to prolonged atmospheric exposure. This 10-min post anneal further stabilized the resistance values. When the resistors were tested, a value of 95 ohms per square was obtained.

3.6 Vacuum-Deposited Conductors

Although copper, gold and aluminum have often been used at HDL as thin-film conductors (resistance less than 1 ohm per sq) aluminum (Al) was used as the conductive material in the 30-Mc IF amplifier, because it was to be employed also as the material for capacitor electrodes. From previous experience with thin-film capacitors, it was known that electrodes of either copper or gold frequently short through the dielectric, and even after clearing the shorts, the capacitors, in general, are unreliable. However, when Al is used as the electrodes, the capacitors are not shorted and are stable. The reason the Al capacitors are not shorted is thought to be due to the "self-healing" effect of Al. That is, if there are shorts through the dielectric when the capacitors are made, the very act of measuring the capacitance causes the shorts (i.e. the filaments joining the top and bottom conductor films) to be heated to a very high temperature by the testing current; because this is done at atmospheric pressure, these hot filaments are oxidized, and thereby burned out, remaining clear indefinitely.

Another reason for choosing Al, instead of either copper or gold, is that it adheres well to glass and hence does not require an under-layer of chromium and associated masking and multiple depositions.

The conductors as tested had resistances less than 0.5 ohm per square.

3.7 Vacuum-Deposited Capacitors

An ever-present problem in the deposition of thin-film SiO dielectrics is the occurrence of pin holes in the films. These pin holes seem to be prevalent in SiO films even when great pains have been taken to insure a dust-free substrate. The main problem in the application of SiO as a thin-film dielectric is, obviously, the shorting of the electrodes through these pin holes. Although this problem was solved by using Al as the electrode material, as mentioned above, the existence of the problem was a factor in determining the thickness of films to be used.

Upon rewriting the formula used for determining area of the dielectric in terms of capacitance, $C = \frac{0.0855\ KA}{d}$, it can be seen that C varies inversely with film thickness (d). Theoretically, therefore, the thinner the film, the higher the capacitance. However, experience had shown that the thinner the dielectric, the greater the pin-hole problem. A third consideration was that an adequate dielectric thickness had to be provided to withstand dielectric breakdown at the voltage existing in the circuit. Hence, a compromise thickness had to be found. Experience had shown that 5000 Å was a practical value; films of this thickness were relatively free from pin holes, and the breakdown voltage, calculated from dielectric strength at 5000 Å, was 26 v across the dielectric.

When the capacitors were measured on the 30-Mc IF amplifier substrate, they were found to have capacitances of 0.0011 μf and none were shorted. When a signal was applied to the amplifier, there was a 14-v drop across the capacitor. Similar thin-film capacitors made at HDL have withstood 25 to 75 v before breakdown, indicating that these capacitors are entirely adequate for this application.

3.8 Inserted Components

The inserted components in the 30-Mc IF amplifier were a 2N700 transistor and a hand-wound toroid. The transistor was chosen because its mechanical construction was such that it could easily be sliced to an 0.030-in. thickness, and its size, of course, was extremely important in this application. Other characteristics that made this transistor attractive were good gain at 30 Mc, its low and controllable capacitance, and its availability.

The toroid was especially designed and made for this circuit at HDL. Its low magnetic field and flat construction made it extremely useful for microcircuit application. It used 7 pf of stray capacitance for tuning, at which capacitance the inductance to resonate at 30 Mc was calculated to be 4.0 μh. The toroid had a diameter of 0.180 in. and a thickness of 0.050 in.

The complete parameters of the transistor and toroid were given in the report by Yetter and Hall (ref 1).

3.9 30-Mc IF Amplifier Stage

One of the three circuits had to be discarded because it developed a short circuit in one of its parts. As noted previously, the capacitors, when tested separately, were not shorted and, therefore, the short is not attributed directly to a short through a capacitor dielectric.

Test data for the two remaining circuits are given in table I. These circuits exhibited power gains of 16.5 db and 14.7 db. Upon retesting the 16.5-db circuit after storage for one year in a desiccator at room temperature, the gain was 15.1 db. The bandwidths during these three tests were about 10 Mc.

The value of gain given in reference 1 for the 2D version of the 30-Mc IF amplifier was 100 db (for 5 stages). It can be seen that the gain of the thin-film version of the amplifier (1 stage) compares favorably with that of the 2D version.

A 50-ohm resistance was used as the output termination in order to compare the thin-film 30-Mc IF amplifier stage with the 2D version. It must be noted, however, that a 50-ohm output termination is not the optimum output resistance for maximum gain in the thin-film stage. The optimum output termination resistance was found to be 9.5 ohms for each circuit. When this resistance was used, the maximum gains were found to be 18.3 db and 19.8 db per stage as indicated in table II.

This thin-film amplifier was no smaller than the prior 2D amplifier. The significant accomplishment lies in the substitution of vacuum-deposited thin-film resistors, conductors, and capacitors for conventional printed and inserted parts. When active parts can be made by thin-film techniques, and a complete thin-film circuit made, the potential of thin-film circuits in microminiaturization can be realized.

4. CONCLUSIONS

(1) Two operating 30-Mc IF amplifier stages have been constructed from vacuum-deposited thin-film conductors, resistors, and capacitors, and an inserted coil and transistor. These amplifiers have power gains of 15.1 db and 14.7 db and a bandwidth of about 10 Mc. Although these parameters are equally dependent upon the active and passive parts, they are significant because they show that suitable vacuum-deposited conductors, resistors, and capacitors were built into an operating circuit.

(2) New techniques developed in constructing this amplifier included the application of a spark-erosion machine to cut slots as narrow as 0.010 in. through a stack of twelve stainless-steel masks with a maximum variation in width of only 0.0003 in.

(3) The thin metal film resistors, deposited from a vapor of nickel and chromium, can be expected to be more stable than conventional screen-printed carbon composition resistors.

(4) The thin-film capacitors, made from a dielectric layer of silicon monoxide, and electrodes of aluminum, exhibited capacitance values of 0.0011 μf. This constitutes a capacitance of 0.0097 $\mu f/cm^2$, a value near the upper limit for capacitors of this type.

(5) Development of a completely thin-film amplifier, or of any entirely thin-film circuit, awaits the development of thin-film active parts.

5. REFERENCES

1. G. R. Yetter and L. L. Hall, "A 2D 30MC IF Amplifier," DOFL Report No. TR-894, 24 February 1961.

2. W. E. Isler, "Properties of Flat Nickel-Chromium Film Resistors," DOFL Report No. TR-948, 26 June 1961.

3. E. F. Horsey, L. D. Shergalis, Editors, "Proceedings of the Symposium on Microminiaturization of Electronic Assemblies," Hayden Book Company, Inc, New York (1958), p. 31-44.

4. J. Krawczyk, "Tooling for Ultrasonic Machining," American Machinist Metalworking Mfg 106, No. 4, 100-103 (19 Feb 1962).

5. W. E. Isler, "On the Cleaning of Glass Substrates by Exposure to Glow Discharge in Vacuo," Thesis, Howard University, 1959.

6. A. Moll, "Einige Eigenschaften dunner, im elektrischer Felde aufgedampfter Einkristallschechten aus Barium - Strontium titanat," Z. F. Angew. Physick. Bd 10 (1958), p. 412.

7. C. E. Drumheller, "Silicon Monoxide Evaporation Techniques," Kemet Company, October 15, 1960.

8. T. J. Kilduff, A. A. Benderly, "Conductive Adhesive for Electronic Application," Electrical Manufacturing, 61 No. 6, 148-152 (June 1958).

9. A. A. Benderly, "Stable, High Temperature Precision Resistors Produced by High Vacuum Evaporation of Thin Metal Films," NBS Report No. 13-562R, 4 August 1953.

10. P. Benjamin, C. Weaver, "Adhesion of Metal Films to Glass," Proceedings of the Royal Society, A, 252, 1960, pp 177-183.

6. ACKNOWLEDGMENT

The authors recognize that valuable contributions by HDL personnel were instrumental in the final item and wish to acknowledge their help, particularly that of B. A. Williams and R. Hessler, in preparing the stainless-steel masks, W. Thiebeau, in preparing the substrate-mask holder, G. R. Yetter, in checking the electrical characteristics of the amplifier, and W. E. Isler and G. G. Avis, in consulting in the field of thin films.

Table I. Electrical Characteristics of the 30-Mc IF Amplifier Stage

	No. 1		No. 2
	Original values	Retest after one year	Original values
Gain (db)	16.5	15.1	14.7
Center frequency (Mc)	35.3	35.0	32.0
Bandwidth (Mc)	30.2-41.7	30.2-39.6	27.3-37.8
V_{cc} (v)	-14	-14	-14
V_{ee} (v)	+14	+14	+14
I_c (ma)	3.0	3.4	4.0
I_e (ma)	3.7	3.7	4.3
Input termination (ohms)	50	50	50
Output termination (ohms)	50	50	50
V_{in} (mv)	15.0	17.5	18.5
V_{out} (mv)	100	100	100

Table II. Maximum Gain of the 30-Mc IF Amplifier Stage

	No. 1	No. 2
Gain (db)	18.3	19.8
Center frequency (Mc)	37.4	36.2
Bandwidth (Mc)	33.2-41.0	31.8-39.8
V_{cc} (v)	-14	-14
V_{ee} (v)	+14	+14
I_c (ma)	3.4	4.0
I_e (ma)	3.7	4.3
Input termination (ohms)	50	50
Output termination (ohms)	9.5	9.5
V_{in} (mv)	27.9	23.4
V_{out} (mv)	100	100

DISTRIBUTION

NOTE: Corrections to the following list would be appreciated and should, along with the report number, be addressed to Department of the Army, Harry Diamond Laboratories, Washington 25, D. C. Attn: Technical Reports Unit.

Commanding General
U. S. Army Materiel Command
Washington 25, D. C.
Attn: AMCCG

Commanding General
U. S. Army Materiel Command
Washington 25, D. C.
Attn: AMCDC

Commanding General
U.S. Army Materiel Command
Washington 25, D. C.
Attn: AMCSA-SC

Commanding General
U. S. Army Materiel Command
Washington 25, D. C.
Attn: AMCRD-TI

Commanding General
U.S Army Materiel Command
Washington 25, D. C.
Attn: AMCRD-PP

Commanding General
U. S. Army Materiel Command
Washington 25, D. C.
Attn: AMCRD-RS

Commanding General
U. S. Army Materiel Command
Washington 25, D. C.
Attn: AMCRD-DE

Office of the Director of Defense Research and Engineering
The Pentagon, Washington 25, D. C.
Attn: Technical Library (rm 3E1065) - 2 copies

Commanding General
U.S. Army Munitions Command
Frankford Arsenal
Philadelphia 37, Pennsylvania

Commanding General
Aberdeen Proving Ground, Maryland
Attn: STEAP-TL, Tech Library (Bldg. 313) - 2 copies
Attn: Tech Library, Br No. 3, Bldg. 400, D and P Services.

DISTRIBUTION (Cont'd)

Commanding General
U. S. Army Munitions Command, Building 151
Dover, New Jersey

Commanding General
U. S. Army Weapons Command
Rock Island, Illinois
  Attn: AMSWE-IE

Commanding Officer
U. S. Army Electronics Research and Development Laboratory
Fort Monmouth, New Jersey
  Attn: Electronic Components Research Dept.

Commanding Officer
U. S. Army Research Office
Duke Station
Durham, North Carolina

Office for the Asst Chief of Staff for Intelligence
The Pentagon, Washington 25, D. C.
  Attn: Mail and Records Branch

Commanding Officer
Foreign Science and Technology Center
Washington 25, D. C.
  Attn. AMXST-SD-TD

Commanding General
Engineer Research and Development Laboratories
U. S. Army
Fort Belvoir, Virginia
  Attn: Technical Documents Center

Commanding General
Headquarters, US Continental Army Command
Fort Monroe, Virginia

Commanding General
Tank-Auto Command
1501 Beard Street
Detroit, Michigan

Commanding Officer
U. S. Army Biological Laboratories
Fort Detrick
Frederick, Maryland

DISTRIBUTION (Cont'd)

Department of the Navy
Chief of Naval Operations
The Pentagon, Washington 25, D. C.
Attn: Research and Development

Department of the Navy
Washington 25, D. C.
Attn: Chief, Office of Naval Research (Bldg T-3)

Commander
U. S. Naval Ordnance Laboratory
White Oak, Silver Spring 19, Maryland

Department of the Navy
Bureau of Naval Weapons
Washington 25, D. C.
Attn: DLI-3, Technical Library

Commander
Naval Research Laboratory
Washington 25, D. C.
Attn: Solid-State Electronics Br., S. Paull

Commander
U. S. Naval Ordnance Test Station
China Lake, California
Attn: Technical Library

Commander
U. S. Naval Air Missile Test Center
Point Mugu, California

Headquarters
U. S. Air Force
Washington 25, D. C.

Department of the Air Force
Deputy Chief of Staff for Development
The Pentagon, Washington 25, D. C.
Attn: Director of Research and Development

Commander
Air Research and Development Command
Andrews Air Force Base
Washington 25, D. C.

Commander
Air Materiel Command
Wright-Patterson Air Force Base, Ohio

Commander
Rome Air Development Center
Griffis Air Force Base, New York

DISTRIBUTION (Cont'd)

Commander
Armed Services Technical Information Agency
Arlington Hall Station
Arlington 12, Virginia
  Attn: TIPDR (10 copies)

Commandant
U. S. Marine Corps
Washington 25, D. C.

National Aeronautics and Space Administration
1520 H Street N. W.
Washington 25, D. C.
  Attn: Div of Research Information

National Aeronautics and Space Administration
Greenbelt, Maryland
  Attn: GSFC, B. Mermelstein (10 copies)

National Security Agency
Fort George G. Meade, Maryland
  Attn: T. A. Prugh

National Bureau of Standards
Washington 25, D. C.
  Attn: Library

Boulder Laboratories
National Bureau of Standards
Boulder, Colorado
  Attn: Library

U. S. Atomic Energy Commission
Washington 25, D. C.
  Attn: Technical Reports Library

Director
Advanced Research Projects Agency
Washington 25, D. C.
  Attn: Chief, Technical Operations Div

Sandia Corporation
Sandia Base
Albuquerque, New Mexico

Los Alamos Scientific Laboratory
Los Alamos, New Mexico
  Attn: R. Watt/J-16

Air Force Cambridge Research Center
Bedford, Massachusetts
  Attn: R. Roberts

DISTRIBUTION (Cont'd)

U. S. Atomic Energy Commission
Germantown, Maryland
Attn: Div of Military Applications (DMA)

INTERNAL (Cont'd)

Horton, B. M./McEvoy, R. W., Lt Col.
Apstein, M./Gerwin, H. L./Guarino, P. A./Kalmus, H. P./Spates, J. E.
Hardin, C. D., 100
Sommer, H., 200
Hatcher, R. D., 300
Hoff, R., 400
Nilson, H., 500
Flyer, I. N., 600
Campagna, J. H., 700
DeMasi, R., 800
Landis, P. E., 900
Seaton, J. W., 260
Scales, J., 920
Barnett, C. W. H , 920
Allen, F., 940
Klute, C. H., 920
Kaiser, Q. C., 920
Hall, L. L., 920
Harrison, E. H., 920
Svanholm, J. K. V., 920
Williams, D., 920
Doctor, N. J., 920
Horsey, E. F./Benderly, A. A., 910
Boesman, W. C., 910 (20 copies)
Technical Reports Unit, 800
Technical Information Office, 010 (10 copies)
HDL Library (5 copies)

(Two pages of abstract cards follow)

AD ______________ Accession No. ______________
Harry Diamond Laboratories, Washington 25, D. C.

A MICROMINIATURE AMPLIFIER WITH THIN-FILM PASSIVE PARTS
B. Mermelstein and W. C. Boesman
TR-1119, 26 April 1963, 21 pp text, 7 illus, XAS-W-251
AMCMS-5010.21.83701, HDL Proj. 94892 UNCLASSIFIED Report

A microminiature 30-Mc IF amplifier stage was fabricated from vacuum-deposited thin-film passive components and two inserted parts. The vacuum-deposited parts, thin films of nickel-chromium, aluminum, and silicon monoxide, were laid down for use as resistors, conductors and dielectrics, respectively. In the deposition processes, dimensionally accurate masks are essential and they were achieved by the use of a spark erosion technique. A specially designed mask-and-substrate holder accurately indexed the masks relative to the substrates.

Three models of this amplifier were made but one could not be used due to a short in the circuit. The other two circuits showed gains of 16.5 and 14.7 db. When one circuit was retested after storage in a desiccator for one year at room temperature, the gain was 15.1 db.

This amplifier represents the first HDL operating device to employ vacuum-deposited conductors, resistors, and capacitors.

Amplifiers— Microminiature abstract
Thin films—Preparation
Thin films—Application
Thin films—Resistance
Thin films—Dielectric properties
Thin films—Electrical properties
Metal films
Dielectric films

AD ______________ Accession No. ______________
Harry Diamond Laboratories, Washington 25, D. C.

A MICROMINIATURE AMPLIFIER WITH THIN-FILM PASSIVE PARTS
B. Mermelstein and W. C. Boesman
TR-1119, 26 April 1963, 21 pp text, 7 illus, XAS-W-251.
AMCMS-5010.21.83701, HDL Proj. 94892 UNCLASSIFIED Report

A microminiature 30-Mc IF amplifier stage was fabricated from vacuum-deposited thin-film passive components and two inserted parts. The vacuum-deposited parts, thin films of nickel-chromium, aluminum, and silicon monoxide, were laid down for use as resistors, conductors and dielectrics, respectively. In the deposition processes, dimensionally accurate masks are essential and they were achieved by the use of a spark erosion technique. A specially designed mask-and-substrate holder accurately indexed the masks relative to the substrates.

Three models of this amplifier were made but one could not be used due to a short in the circuit. The other two circuits showed gains of 16.5 and 14.7 db. When one circuit was retested after storage in a desiccator for one year at room temperature, the gain was 15.1 db.

This amplifier represents the first HDL operating device to employ vacuum-deposited conductors, resistors, and capacitors.

Amplifiers— Microminiature abstract
Thin films—Preparation
Thin films—Application
Thin films—Resistance
Thin films—Dielectric properties
Thin films—Electrical properties
Metal films
Dielectric films

AD ______________ Accession No. ______________
Harry Diamond Laboratories, Washington 25, D. C.

A MICROMINIATURE AMPLIFIER WITH THIN-FILM PASSIVE PARTS
B. Mermelstein and W. C. Boesman
TR-1119, 26 April 1963, 21 pp text, 7 illus, XAS-W-251.
AMCMS-5010.21.83701, HDL Proj. 94892 UNCLASSIFIED Report

A microminiature 30-Mc IF amplifier stage was fabricated from vacuum-deposited thin-film passive components and two inserted parts. The vacuum-deposited parts, thin films of nickel-chromium, aluminum, and silicon monoxide, were laid down for use as resistors, conductors and dielectrics, respectively. In the deposition processes, dimensionally accurate masks are essential and they were achieved by the use of a spark erosion technique. A specially designed mask-and-substrate holder accurately indexed the masks relative to the substrates.

Three models of this amplifier were made but one could not be used due to a short in the circuit. The other two circuits showed gains of 16.5 and 14.7 db. When one circuit was retested after storage in a desiccator for one year at room temperature, the gain was 15.1 db.

This amplifier represents the first HDL operating device to employ vacuum-deposited conductors, resistors, and capacitors.

Amplifiers— Microminiature abstract
Thin films—Preparation
Thin films—Application
Thin films—Resistance
Thin films—Dielectric properties
Thin films—Electrical properties
Metal films
Dielectric films

AD ______________ Accession No. ______________
Harry Diamond Laboratories, Washington 25, D. C.

A MICROMINIATURE AMPLIFIER WITH THIN-FILM PASSIVE PARTS
B. Mermelstein and W. C. Boesman
TR-1119, 26 April 1963, 21 pp text, 7 illus, XAS-W-251.
AMCMS-5010.21.83701, HDL Proj. 94892 UNCLASSIFIED Report

A microminiature 30-Mc IF amplifier stage was fabricated from vacuum-deposited thin-film passive components and two inserted parts. The vacuum-deposited parts, thin films of nickel-chromium, aluminum, and silicon monoxide, were laid down for use as resistors, conductors and dielectrics, respectively. In the deposition processes, dimensionally accurate masks are essential and they were achieved by the use of a spark erosion technique. A specially designed mask-and-substrate holder accurately indexed the masks relative to the substrates.

Three models of this amplifier were made but one could not be used due to a short in the circuit. The other two circuits showed gains of 16.5 and 14.7 db. When one circuit was retested after storage in a desiccator for one year at room temperature, the gain was 15.1 db.

This amplifier represents the first HDL operating device to employ vacuum-deposited conductors, resistors, and capacitors.

Amplifiers— Microminiature abstract
Thin films—Preparation
Thin films—Application
Thin films—Resistance
Thin films—Dielectric properties
Thin films—Electrical properties
Metal films
Dielectric films

REMOVAL OF EACH CARD WILL BE NOTED ON INSIDE BACK COVER, AND REMOVED CARDS WILL BE TREATED AS REQUIRED BY THEIR SECURITY CLASSIFICATION.